Electron cloud effects in hadron colliders

L. Mether (EPFL), G. Rumolo (CERN)

With input from: I. Bellafont, E. Belli, L. Carver, G. Iadarola,
R. Kersevan, K. Li, K. Ohmi, A. Romano, M. Schenk, F. Zimmermann

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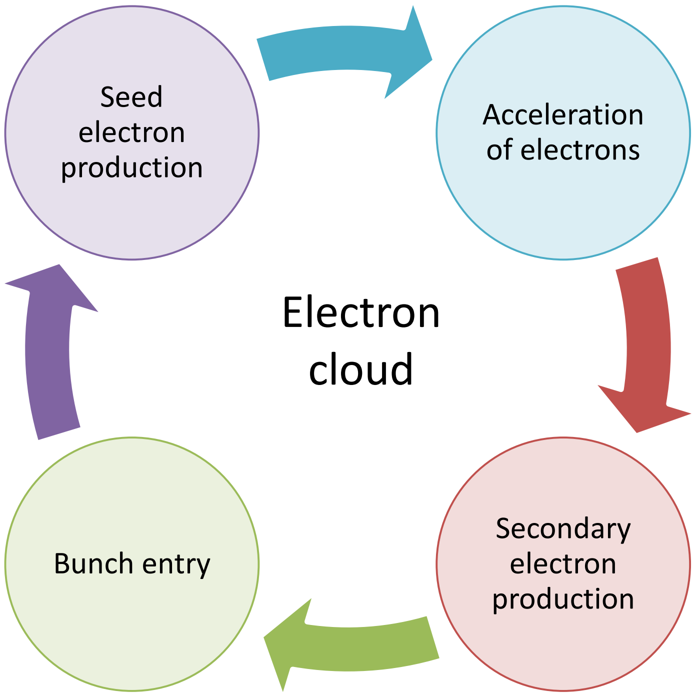
Electron cloud build-up



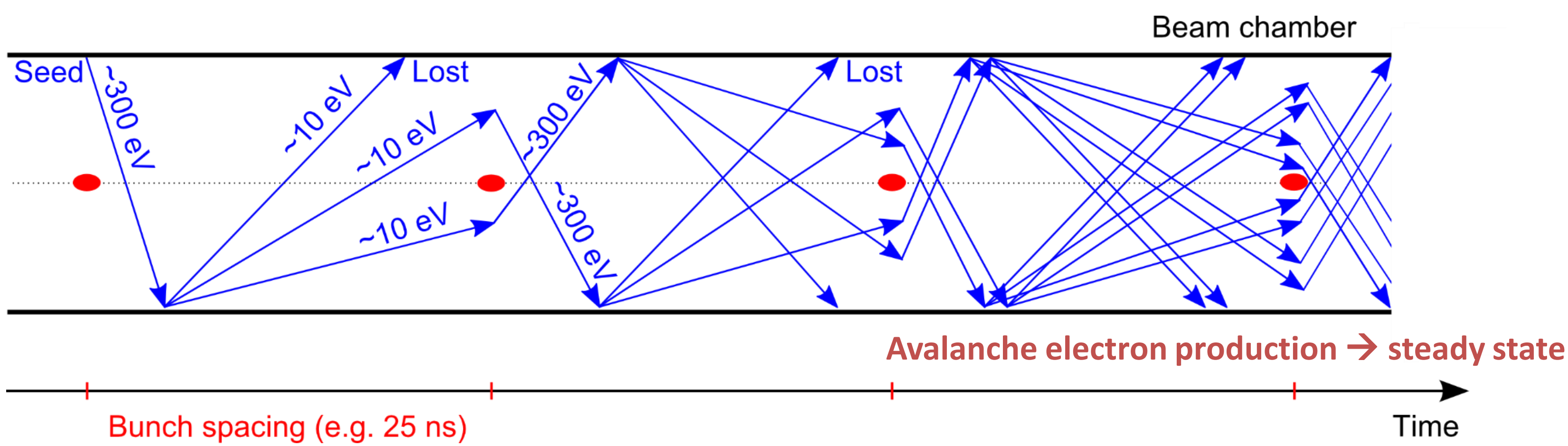
$$\delta(E) = \frac{I_{\text{emit}}}{I_{\text{imp}}(E)}$$

Secondary Electron Yield (SEY)

- Ratio between emitted and impacting electron current, as function of the energy of the impinging electrons

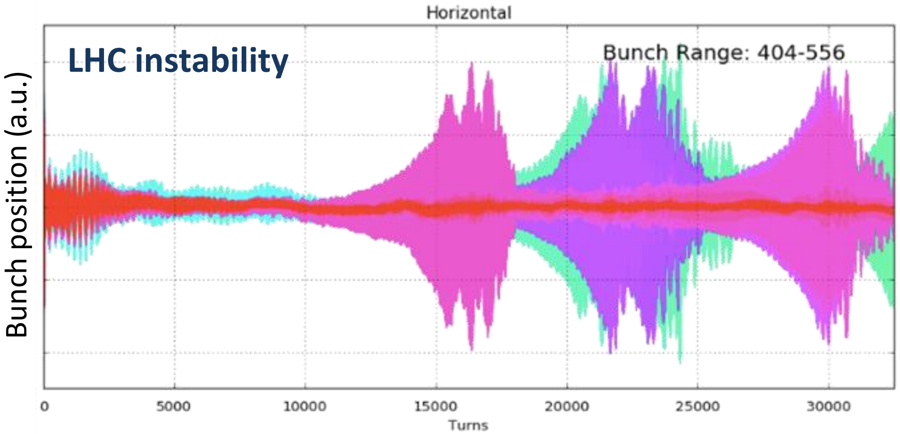
Seed electron production

- Residual **gas ionization**
- **Photoelectrons** from synchrotron radiation
- Desorption

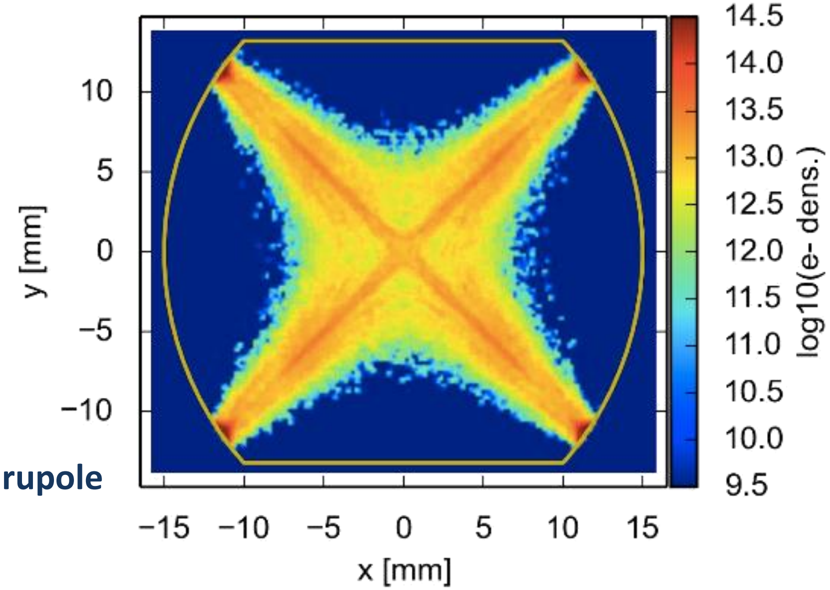


Effects of electron cloud

- Beam dynamics: trailing bunches interact with a dense e-cloud
  - **Transverse instabilities**
  - Tune shift & spread
  - → **Emittance growth**
  - → Beam loss & poor lifetime



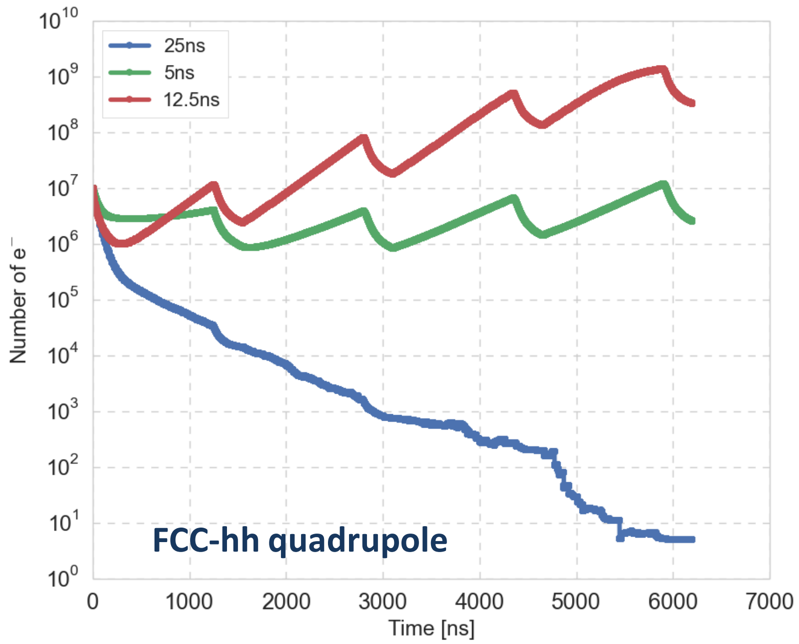
- Machine conditions: electrons impacting on the chamber wall
  - **Additional heat load** → potential problem in cryogenic machine (limited cooling capacity)
  - Outgassing, fast **pressure rise** → danger for sensitive equipment

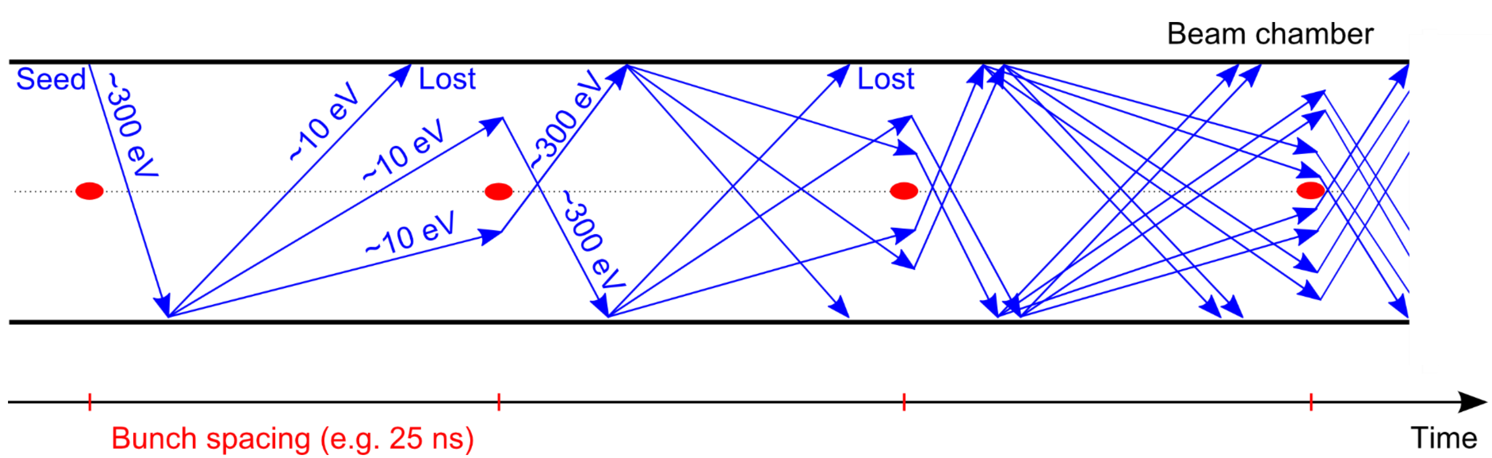


FCC-hh quadrupole

Ingredients for e-cloud build-up

- A multi-disciplinary problem that is the sum of several key ingredients
- Beam screen:
  - Transverse size and geometry
- Beam parameters
  - Bunch intensity and length
  - Bunch spacing → how many electrons are lost before the next bunch
- Magnetic fields
  - Electrons trapped around field lines

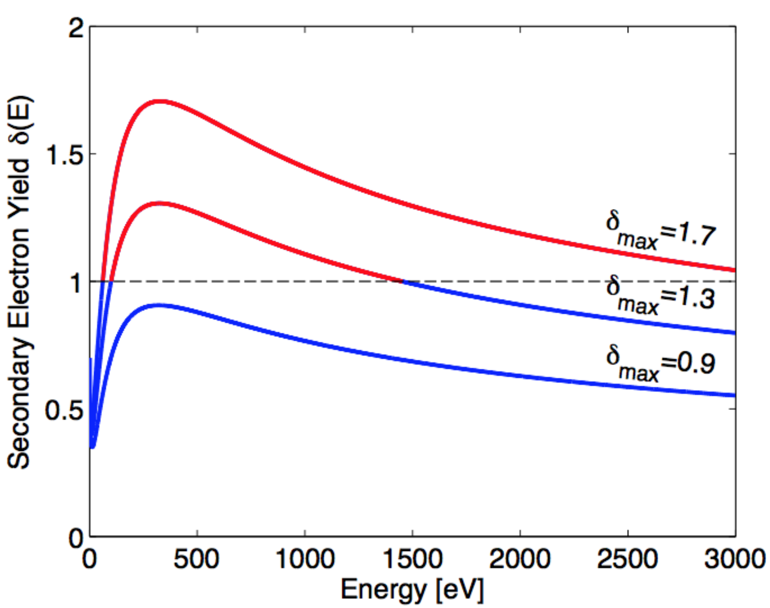


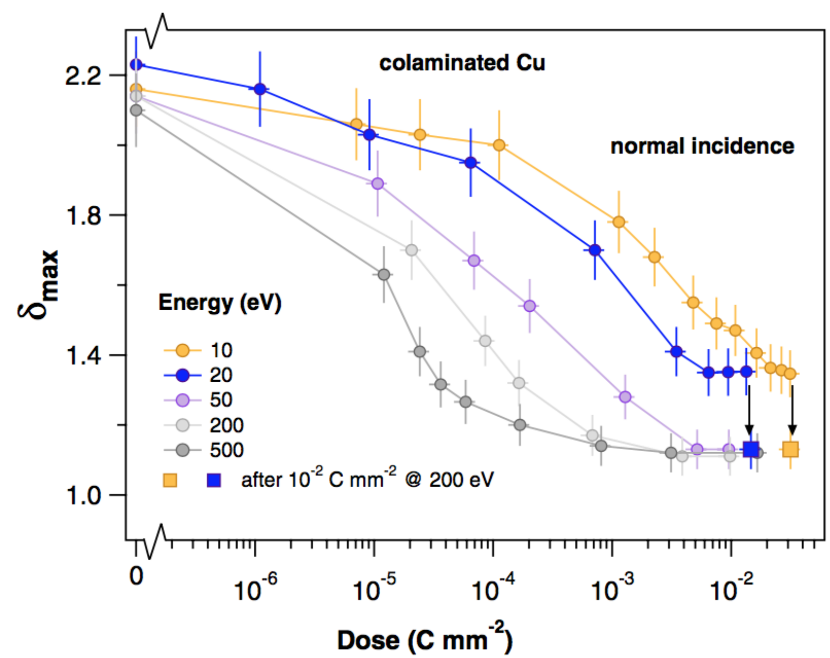


Ingredients for e-cloud build-up

- A multi-disciplinary problem that is the sum of several key ingredients
- Beam screen:
  - Surface properties:
    - Secondary electron yield, but also photoelectron yield, (photon reflectivity)

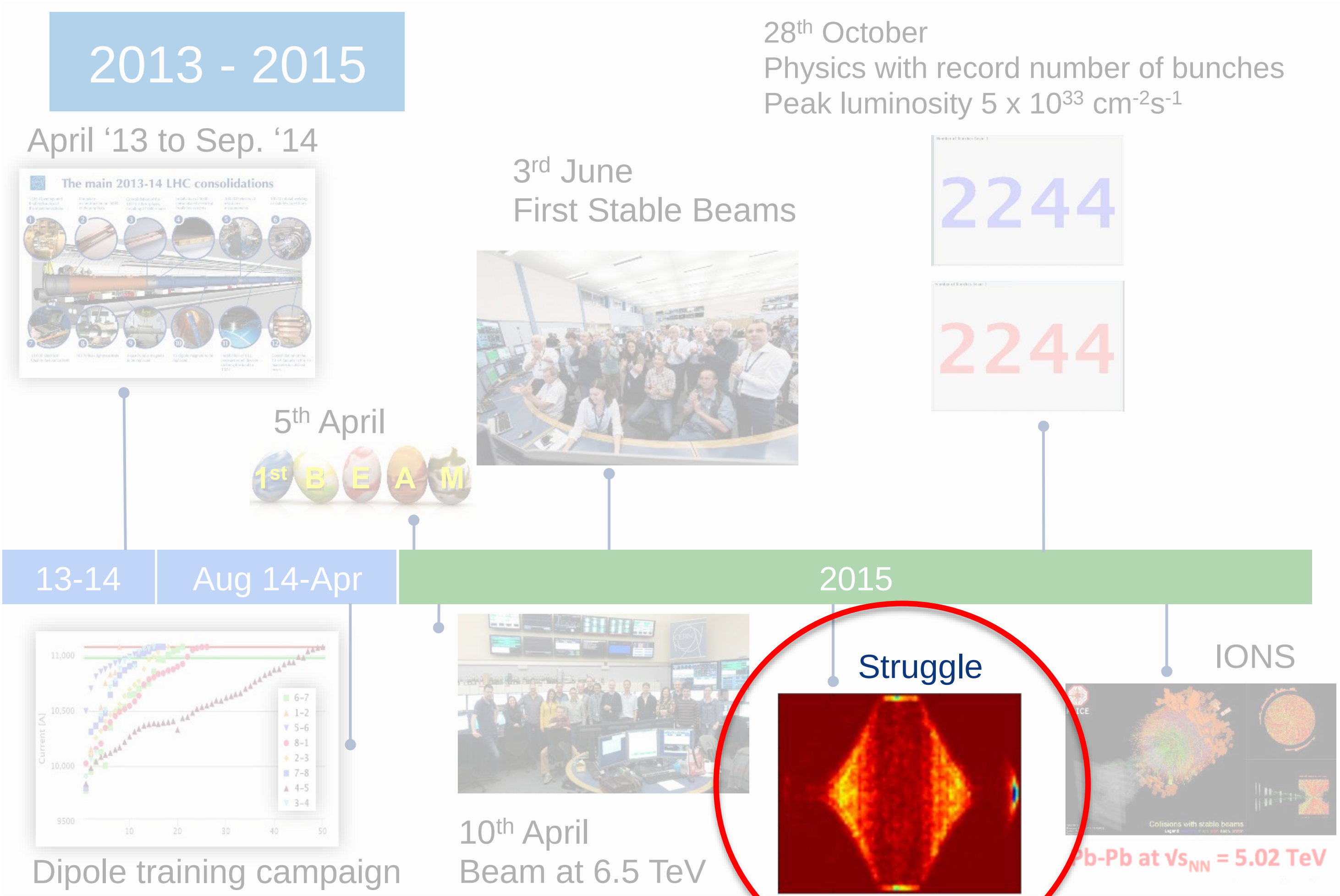
    → Surface chemical properties, roughness
  - Also history of the surface, in particular accumulated electron dose:
    - To a certain extent the e-cloud cures itself → beam induced scrubbing





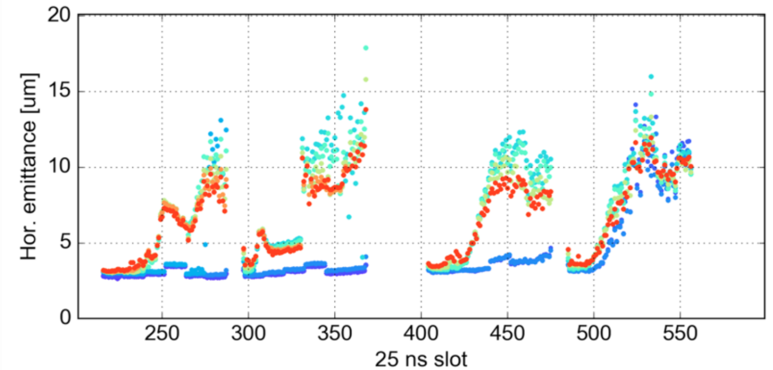
R. Cimino et al. Phys. Rev. Lett. **109**, 064801 – 2012

E-cloud in the LHC

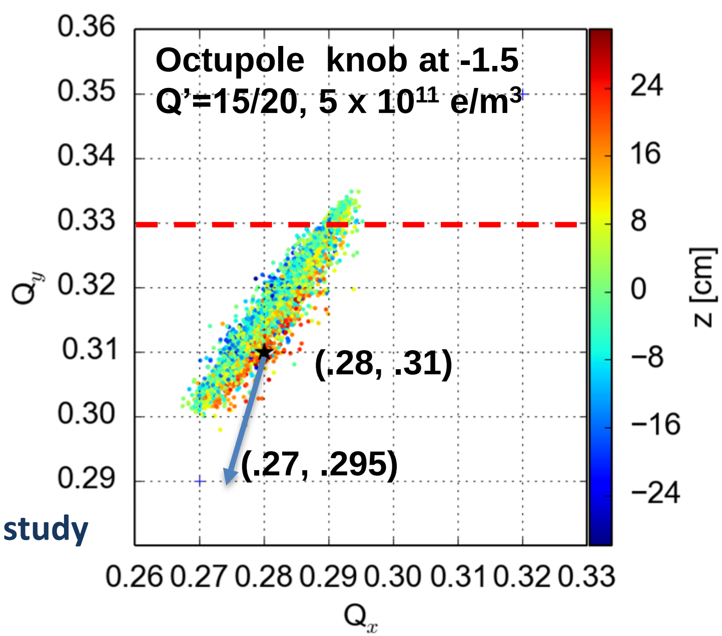


LHC in 2015: beam stability

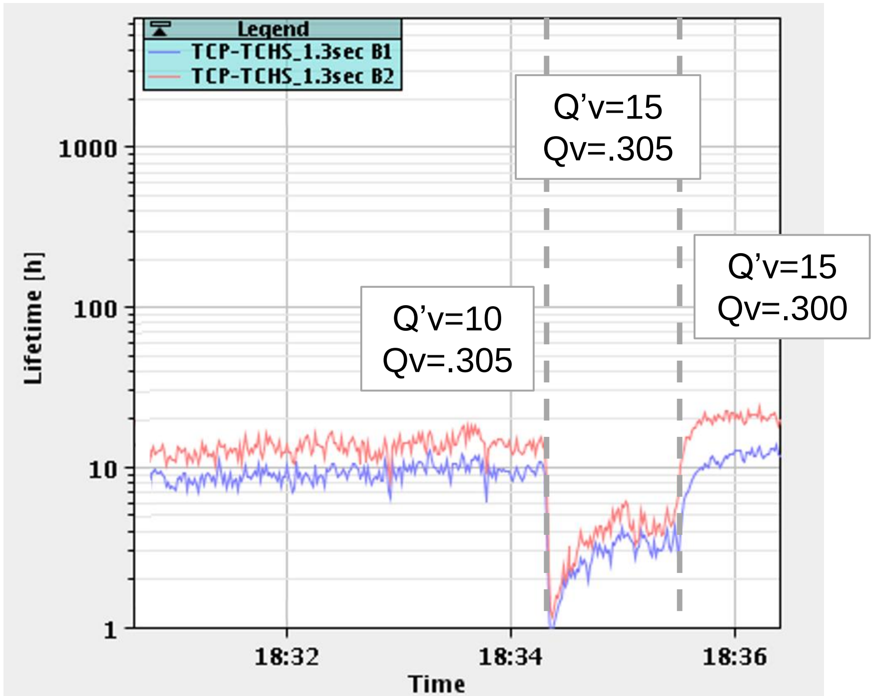
- Strong e-cloud in the machine → difficult to maintain beam stability
  - Optimized operational settings to preserve transverse emittances
    - Strong feedback
    - High chromaticity ($Q'_{H/V}$=20)
    - High octupole settings ($\Delta Q = 1.5 \times 10^{-3}$)



  - Optimized tunes at injection to accommodate tune footprint from Q', octupoles and e-cloud

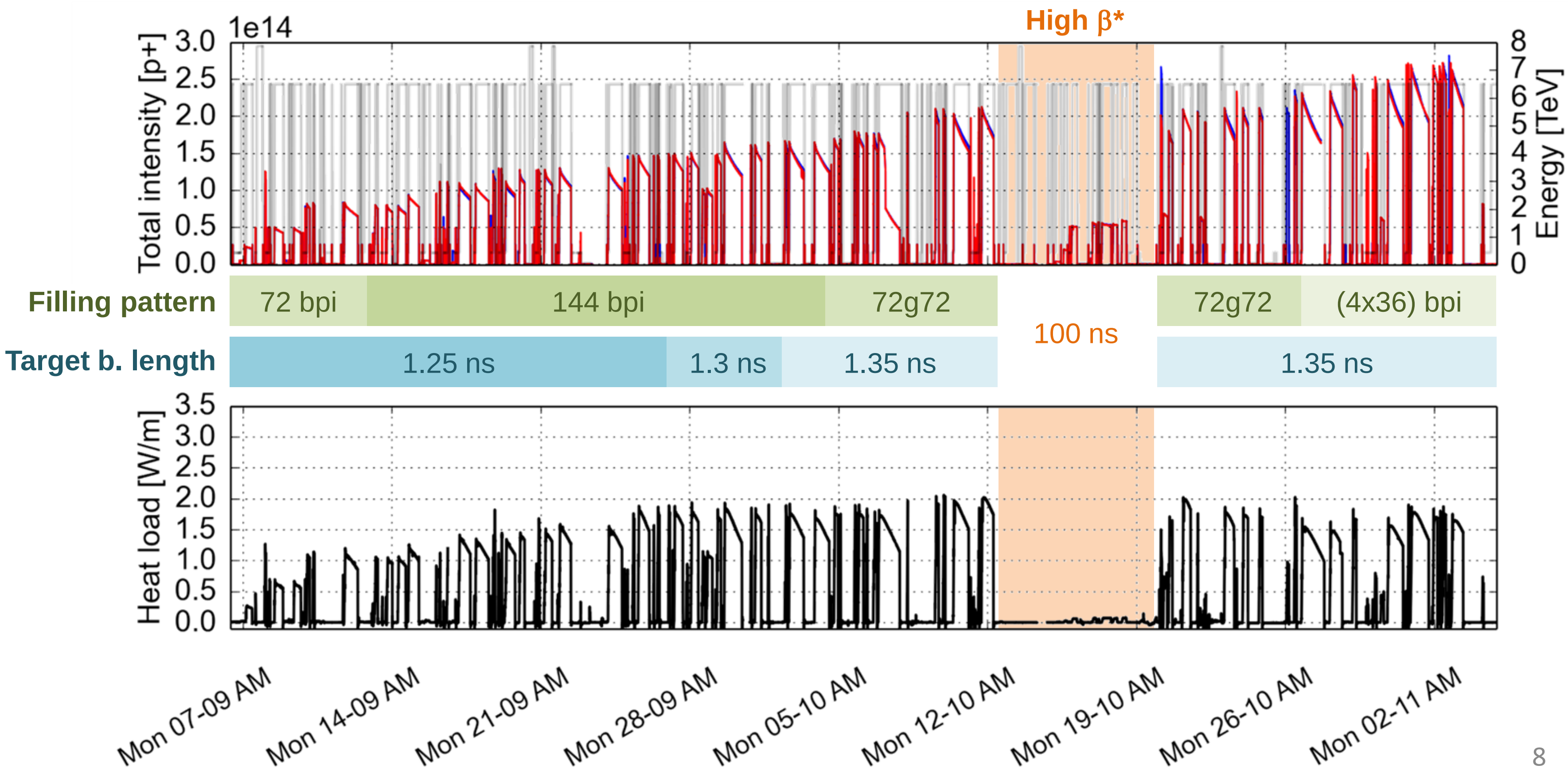


Simulation study



LHC in 2015: heat load

- Approached limit of cooling capacity on arc beams screens with ~1450 b.
- Additional margin could be gained by:
  - Increased longitudinal emittance blow-up on the ramp → longer bunches
  - Optimized filling scheme to gain additional margin → shorter trains
  - Scrubbing



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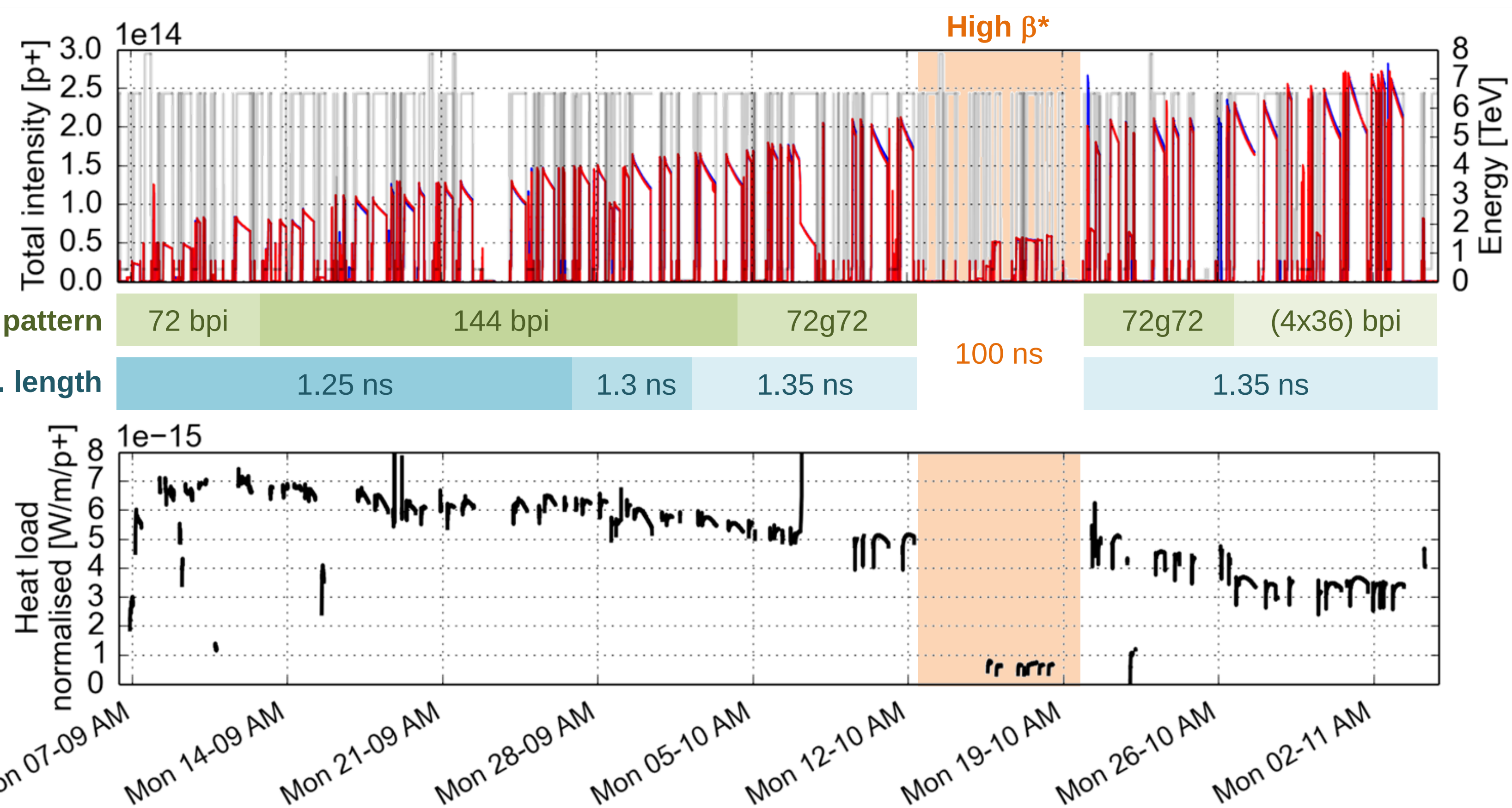
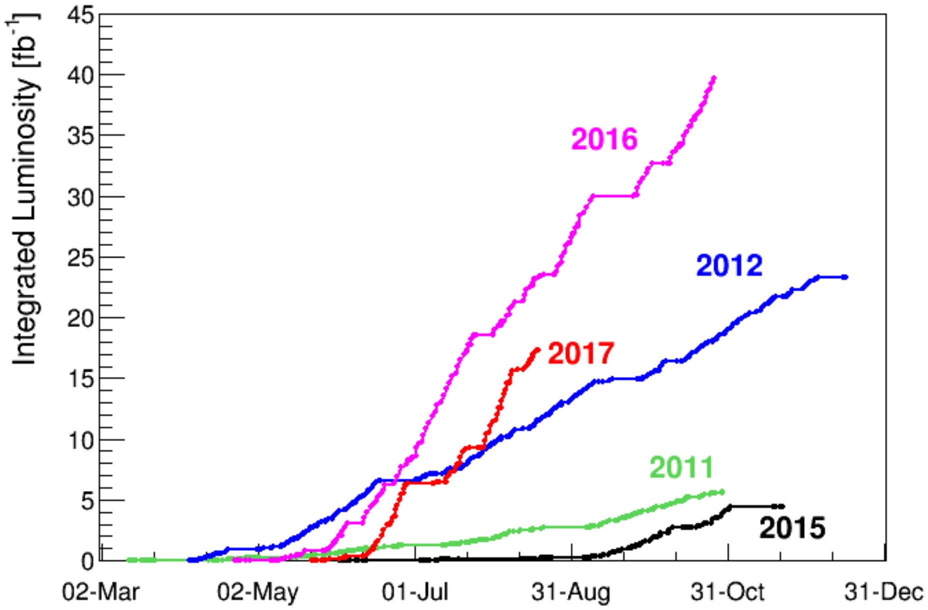
→ **Heat load/bunch significantly decreased during the physics run**



Lessons from the LHC

- LHC is still running with considerable e-cloud
  - – The design number of bunches (2760) could not currently be accelerated
  - \+ The beam quality is good
  - \+ The performance is very good
  - \+ Records in 2017:
    - **1.75 x10^{34} cm^{-2}s^{-1} peak luminosity**
    - **2460 bunches**

Running a collider with e-cloud is a struggle, but not hopeless!



When designing future hadron colliders, e.g. HE-LHC or FCC-hh, we should aim to avoid the struggle and make the machines e-cloud free from the beginning

E-cloud in FCC-hh

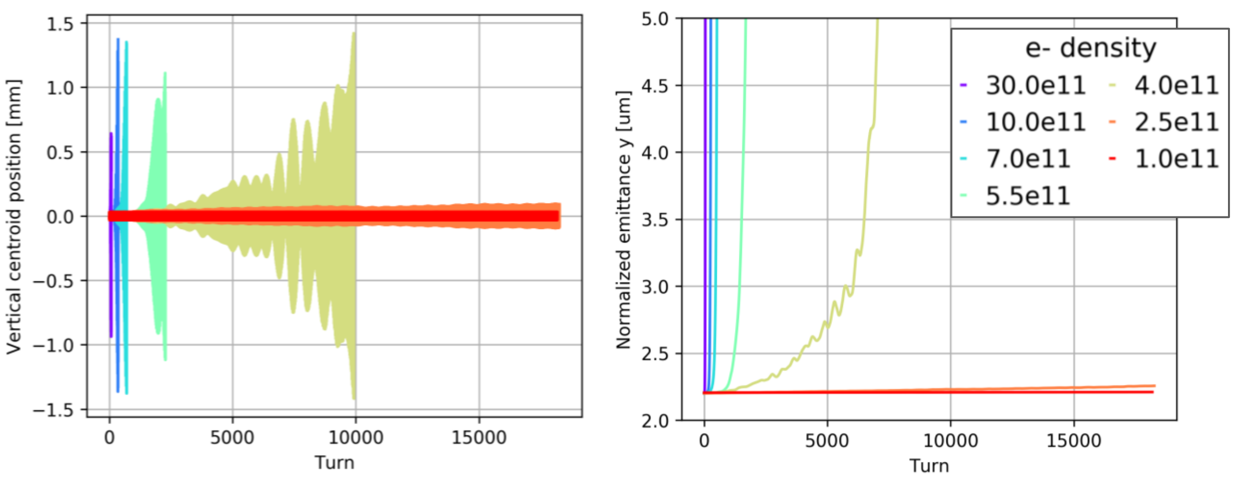
- E-cloud build-up can be suppressed by
  - **Minimizing the SEY** with **surface treatments**, e.g. a-C coating
  - **Suppressing seed electrons** also beneficial, e.g. FCC-hh beam chamber design

    → To understand to what extent these measures are required, complete simulation studies of e-cloud build-up and instability are necessary

- E-cloud induced instability simulations are a multi-scale study
  - **In space**: small beam (100 um) in a big chamber (3 cm)
  - **In time**: e^- motion resolved to ns scale, instability development can take ~10 s

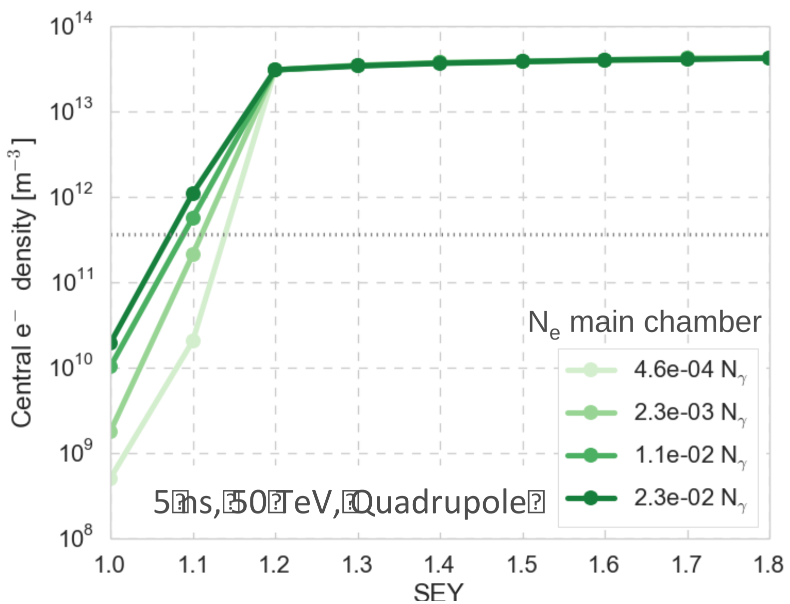
    → A single simulation may require ~10s of CPU months

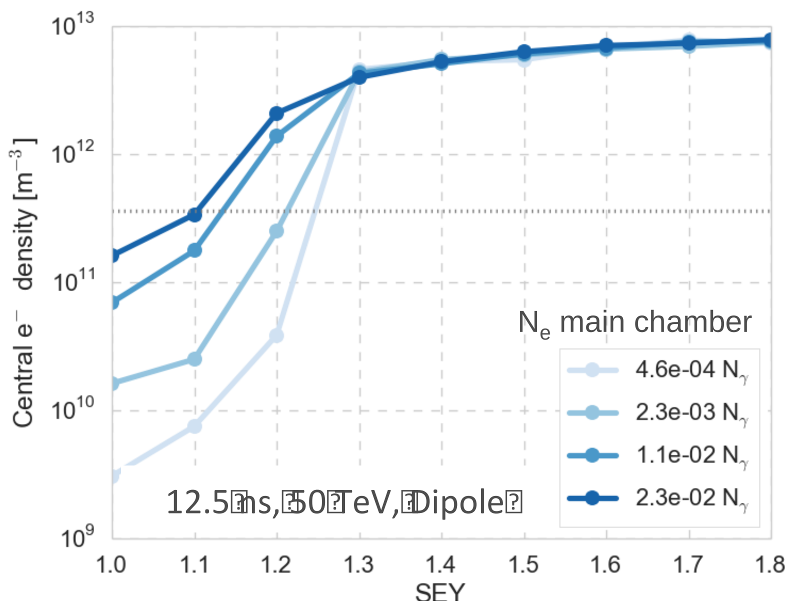
Threshold electron density for instability in FCC-hh dipole for 25 ns beam at 3.3 TeV



E-cloud in FCC-hh

- Build-up simulations show that even for low SEY ~1 – 1.1, electron densities can reach instability threshold due to photoelectrons





- Depending on the number photons that reach the main chamber and the photoelectron yield

  → Iterations with beam screen design to try to suppress further

Summary

- Electron cloud is undesired effect in hadron colliders, with detrimental effects both on beam quality and machine conditions
- Present in the LHC since start of Run 2 (→ 25 ns bunch spacing)
- Design of future accelerators should be such that e-cloud is avoided
- Requires extensive studies to determine constraints
  - Multi-disciplinary → affects design on multiple levels

Thank you!